Concrete Obstacle Vulnerability

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LONG-TERM GOALS

The long-term goals of the research were: (1) to establish vulnerability of finite concrete targets to a variety of warhead technologies, (2) to develop a damage rule which relates obstacle destruction to warhead and obstacle characteristics, and (3) to ultimately understand the ordnance options to break up the concrete blocks into pieces with maximum standing dimensions that will not impede the advance of an Amphibious Assault Vehicle (AAV).

OBJECTIVES

The objectives of the FY98 effort were to wrap up the five-year concrete target vulnerability work with an experimental program that would broaden our assessment of two warhead types against finite concrete obstacles by including the effect of submergence under water. A direct comparison to the break up in air could be made since identical warheads as used in the FY96 and FY97 test program were tested. The warheads planned for the FY98 testing were explosively-formed projectiles (EFPs) (available from the lot specially designed by, and procured from, DE Technologies, Inc. (DET) for the FY96 and FY97 test program) and a 3200 gr/ft Cu/RDX linear-shaped charge (LSC) originally procured from GOEX International. As detailed below, these objectives have been met.

APPROACH

One test of a one foot long LSC into a one-foot 5000 psi (SAC-5) concrete cube was conducted and two tests of 8-inch Copper EFPs against four-foot SAC-5 concrete cubes were conducted. The original plan was to conduct the first test with water surrounding all sides except for the top surface and conduct both full-scale tests with the concrete cubes completely submerged. The data gathering was similar to that done in previous years regarding fragment dimensions and weights. A limited statistical analysis and an extensive compilation of the debris data collected, including the data from the previous years was done. The figure-of-merit (FOM) was computed for all of the tests with penetrators for a check on its ability to correlate with the degree of rubbling achieved.

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WORK COMPLETED

On Thursday, 23 April 1998, the first of three concrete underwater shots was completed. This consisted of statically firing a single LSC into a one-foot concrete cube, constructed by ARL in FY96. The concrete cube was surrounded by water, except for the top surface where the LSC was placed. The water level was brought up to within ½ inch of the top surface of the concrete cube before the test. On Tuesday 28 April 1998, the second of the underwater shots was completed. This consisted of statically firing the 8-inch Cu-1 one-piece EFP into a four-foot concrete cube. The concrete obstacle was submerged in water in the tank which has inside dimensions of 141" x 140" x 72.5". There was a 19-inch water overburden. The third test was conducted on 1 May 1998. Changes from the original plan were made to the test condition for this third test based upon the results of the first two tests, as described in the next section. The results of these tests and all the tests, analyses, and FOM development efforts from the five-year program were documented in a comprehensive technical report.

RESULTS

A first look at the resulting break up of the one-foot block from the LSC test, shown in the top left photo of Figure 1, was strikingly similar to the break up in air of the two blocks tested and analyzed in FY96 (shown in the right photo of Figure 1): the formation of a pyramidal-shaped center region and comparable rubbling of the remainder of the cube. It was anticipated that less break up would have occurred; however, since the top surface was not submerged, this free surface with its impedance mismatch may have been the sufficient condition for the degree of rubbling observed.

The test of the 8-inch Cu-1 one-piece EFP into a four-foot concrete cube with a 19-inch water overburden produced significantly less rubbling than those of the 8-inch EFPs on concrete in air. This was expected, considering the significant reduction in impedance mismatch between the cube and its surroundings with the entire cube submerged. The pre-test and post test conditions are shown in Figure 2. Approximately half the cube mass was still standing in position, although this mass was broken into a number of large pieces. Those pieces did not scatter under water. Only a couple of pieces (about 1 foot long) were thrown out of the tank about 10 feet.

Based on the results of the first two tests, a change in the test condition for the third and last water shot was made. For this last test (using an 8-inch Cu-2 stretchy EFP), the water level was brought to within 1 inch of the top surface, leaving the top surface exposed to air. Considering that both designs of the 8-inch EFPs in air were tested (in FY97) against cylinders and cubes and the rubbling was comparable in all four of these tests (implying that both EFPs should do a comparable job on a cube that is completely submerged), it was considered more worthwhile to find out through this last test whether keeping the top surface exposed to air would result in much better rubbling. The hunch was that, as in the one-foot cube test, one free surface may be a sufficient condition to produce significant rubbling. This would be a significant result if one expected that cubes in the surf zone would at least be partially above the water, depending on the tides and obstacle placement.

The hunch proved to be correct. The resulting rubbling was far greater than the test with the 19-inch water overburden. Pieces were blown up to 50 feet away from the tank. The pre-test and post test

conditions are shown in Figure 3. This is a significant result that has optimistic implications for the defeat of concrete obstacles that are in the surf zone but not completely submerged.

Summary Rubbling Table. Table 1 summarizes all of the tests done on this program except for the tests of the one-foot cubes. The right-hand column gives the FOM for each penetrator computed in accordance with the FOM described in the technical report in press (Reference 1) and based upon the penetrator and target geometry and materials and the level of kinetic energy (KE) delivered to the obstacle by each penetrator.

As is apparent from the discussion in Reference 1, the rubbling percentage quoted for a given penetrator and obstacle is a somewhat arbitrary measure. That is, 100 percent rubbling for a four-foot cube simply means the largest fragment is not larger than 16 inches; an obstacle that is not 100 percent rubbled means fragments remain that are larger than 16 inches. Further, the fragment dimension used in this measure can be its maximum dimension or it can be something else such as the fragment's standing height or lateral dimension. It should also be noted that in Table 1, the 16-inch measure is scaled down for the smaller cubes. Percent rubbling relative to maximum dimensions is the measure used in the development of the FOM. Percent rubbling relative to minimum dimensions is a measure used to approximate the degree of clearance from the standpoint of the underbody clearance of an AAV. In neither case is the measure presumed to be the same thing as a probability of passage of any vehicle through an obstacle field. In other words, while 100 percent rubbling implies a 100 percent probability of passage, there is not a lesser value correspondence.

Judging from the overall rubbling percentages and computed figures-of-merit (referring to the FOM for penetrators), a recommended FOM to be achieved in a penetrator to incur "substantial" rubbling of a finite concrete obstacle would be on the order of 100; a FOM in the 200 to 300 range would be preferred. Even then, 100 percent rubbling by either definition is not assured, particularly when deviating from the ideal placement of the penetrator (i.e., on center). In general terms, a high rubbling capability is expected from a penetrator which (1) penetrates deep, but is fully consumed (eroded) in the first half of the target, (2) has a large diameter, and (3) has high KE.

IMPACT/APPLICATIONS

This task will have an impact on the eventual decisions of what systems are developed or deployed for the obstacle-breaching mission. The impact will be a result of warhead technology selections made during an analysis of alternatives for this mission. The general understanding of concrete defeat and the damage rule developments has already been applied to a concept assessment task (warhead lethality estimates) for the Coastal Systems Station of the Naval Surface Warfare Center, Dahlgren Division (NSWCDD) at Panama City, Florida.

TRANSITIONS

Although there is no current 6.3 or 6.4 Obstacle Clearance program in the Navy, PMS407 is expected to perform an Analysis of Alternatives (AOA) in 2003. It is expected that this effort will provide the necessary technical input to the AOA and will develop the insights to guide the resulting engineering development programs.

RELATED PROJECTS

The Indian Head Division, Naval Surface Warfare Center funded, as part of its Technology Investment Program, a task to investigate the 500 pound-class CRW technology for application to obstacle clearance, including attack of four-foot SAC-5 concrete cubes and a variety of other full scale targets.

Leading researchers from the DOD and DOE Labs, funded in large part by the Defense Special Weapons Agency, have been developing, on an on-going basis, analytical tools, a materials and constitutive modeling data base, and an extensive testing data base for the penetration technology of missiles and other penetrators into soils, rock, and concrete. The work is coordinated through the Technology Coordination Group-XI, which meets semi-annually to bring together the major research and discuss future direction.

Research, including full scale testing, is being conducted as part of the Hypervelocity Weapon Technology program under the sponsorship of ONR. NSWCDD at Dahlgren, Virginia and DE Technologies, Inc. are working together on a concept which places an EFP warhead on the front of a KE missile which is already flying at hypervelocity speeds to facilitate penetration into thick concrete.

REFERENCE

J.R. Renzi, et al, 1998: “Concrete Obstacle Vulnerability,” Naval Surface Warfare Center, Indian Head Division, IHTR 2126, 30 September. (In press.)

PUBLICATIONS

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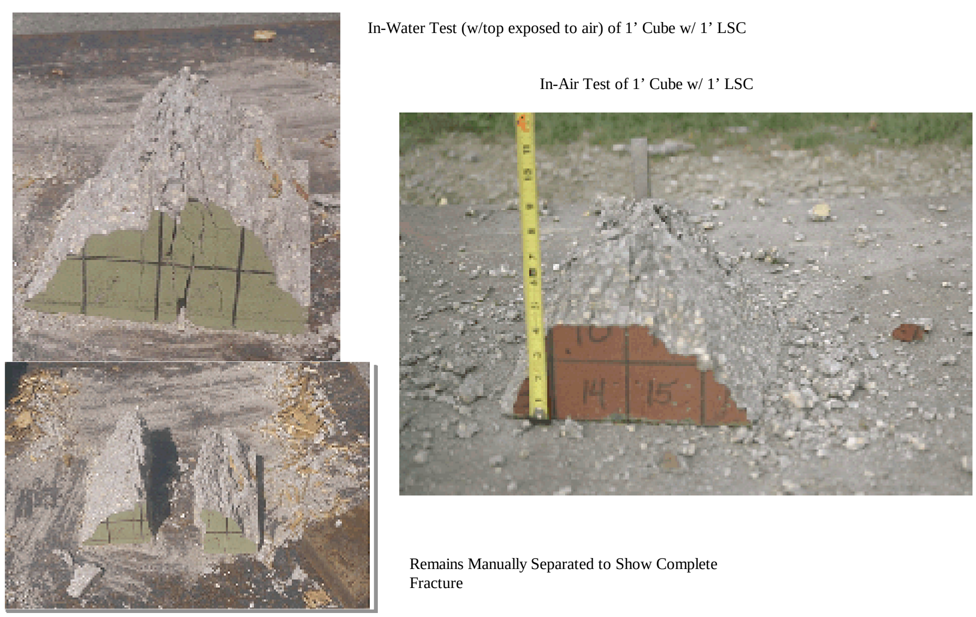
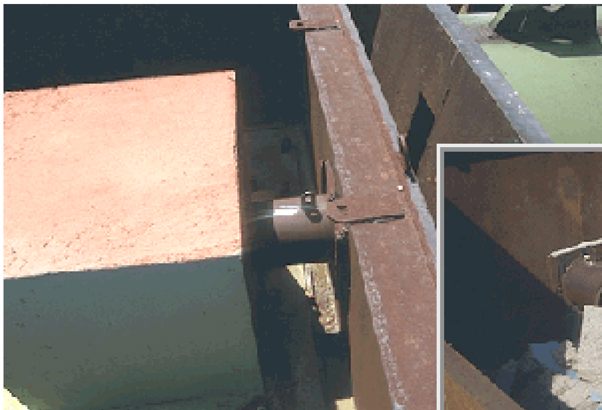


Figure 1. Results of LSC Tests on One-foot Cubes



Test Setup Prior to Water Fill

Post

Figure 2. In-Water Test of 4' Cube (19" water overburden) with 8-inch Cu One-piece EFP

Water Level 1 Inch Below Top Surface

Post Test

Figure 3. In-Water Test of 4' Cube (top exposed to air) with 203 mm Cu SR

Test #	Round Type	Obstacle	Percent rubbling relative to:		FOM (J/m^3)
			Max Dim	Min Dim	
1 & 6	Ta Hemi- SC, 165 mm	48" 2 ksi Cube	30 & 32	-	3.5
2	Cu EFP, 140 mm	48" 2 ksi Cube	44	-	53
7	Cu EFP, 140 mm aimed 1' down, 1' over from center	48" 2 ksi Cube	22	-	53
17	Cu EFP, 140 mm	48" 2 ksi Cube Cube under water	22	-	53
3	Cu Trumpet-SC, 146 mm	48" 2 ksi Cube	3	-	0.2
4	Ta Conical-SC, 152 mm	48" 2 ksi Cube	14	-	0.8
5	Ta EFP, 117 mm	48" 2 ksi Cube	24	-	16
8	Ta EFP, 152 mm	48" 2 ksi Cube	38	-	62
10	Slow Cu EFP, 152 mm	48" 2 ksi Cube	36	-	122
15	120 mm DM-13, W KE Rod	48" 2 ksi Cube	75	-	177
16	120 mm M865, Steel KE	48" 2 ksi Cube	77	-	234
Ob-15	120 mm M865, Steel KE	SAC-5 Column	69	100	256
Ob-16	120 mm M865, Steel KE	SAC-5 Column	68	100	256
Ob-12	120 mm M865, Steel KE Penetrator impacted 6" above center	48" SAC-5 Cube	54	97	234
Ob-8	120 mm DM-13, W KE	48" SAC-5 Cube	75	100	177
Ob-7	Cu SR, 203 mm	48" SAC-5 Cube	85	100	172
Ob-20	Cu SR, 203 mm	SAC-5 Column	98	100	188
Ob-18	Cu EFP, 203 mm	48" SAC-5 Cube	80	96	302
Ob-14	Cu EFP, 203 mm	SAC-5 Column	92	100	330
2-97	Cu EFP, 203 mm	48" SAC-5 Cube	52	68	302
Cube was completely submerged under water with a 19" water overburden.					
5-97	Cu SR, 203 mm	48" SAC-5 Cube	84	97	172
Cube was in water with top surface only exposed to air; i.e., water level was 1" below top surface.					
Ob-3	Cu EFP, 165 mm	48" SAC-5 Cube	67	92	162
Ob-19	Cu SR, 165 mm	48" SAC-5 Cube	51	100	29
Ob-9	Al EFP, 165 mm	48" SAC-5 Cube	66	96	126
Ob-1	105 mm HEP-T M393	48" SAC-5 Cube	61	100	---
Ob-4	105 mm HEP-T M393	48" SAC-5 Cube	60	100	---
Ob-2	125 mm FRAG-HE OF26	48" SAC-5 Cube	77	100	---
24-3	134 lb CRW	24" SAC-5 cube	80	84	102
30-2	134 lb CRW	30" SAC-5 cube	67	83	49
24-2	134 lb CRW	24" SAC-5 cube	74	81	149
30-1	134 lb CRW	30" SAC-5 cube	75	94	69
24-4	134 lb CRW	24" SAC-5 cube	66	72	102
30-3	134 lb CRW	30" SAC-5 cube	66	80	49
24-1	134 lb CRW	24" SAC-5 cube	59	64	65
30-4	134 lb CRW	30" SAC-5 cube	61	82	33
Ob-13	2.268 kg C-4 (2' deep)	48" SAC-5 Cube	100	100	48,862*
Ob-17	0.712 kg C-4 (2' deep)	48" SAC-5 Cube	83	100	6,561*
Ob-6	0.712 kg C-4 (1' deep)	48" SAC-5 Cube	46	90	3,996*
Ob-10	18 LSCs Array (2 faces)	48" SAC-5 Cube	60	-	2.4
Ob-11	6 of 9 LSCs Array (1 face)	48" SAC-5 Cube	9	19	0.79
In follow-up tests, six rounds of 25 mm M793 TP (FOM = 0.76 each) rubbled a large section of Ob-11 pre-damaged from the six LSCs; 16 rounds of 20 mm TP M55A2 20 (FOM = 0.17 each) rubbled the other large section of Ob-11. See text for small arms results on virgin cubes.					

* Different figure-of-merit and scale apply to bulk charges.

Table 1. Summary Rubbling Table